Calibration of a Probe for Strain Sensitivity Studies of Critical Current Density in Superconducting Wires

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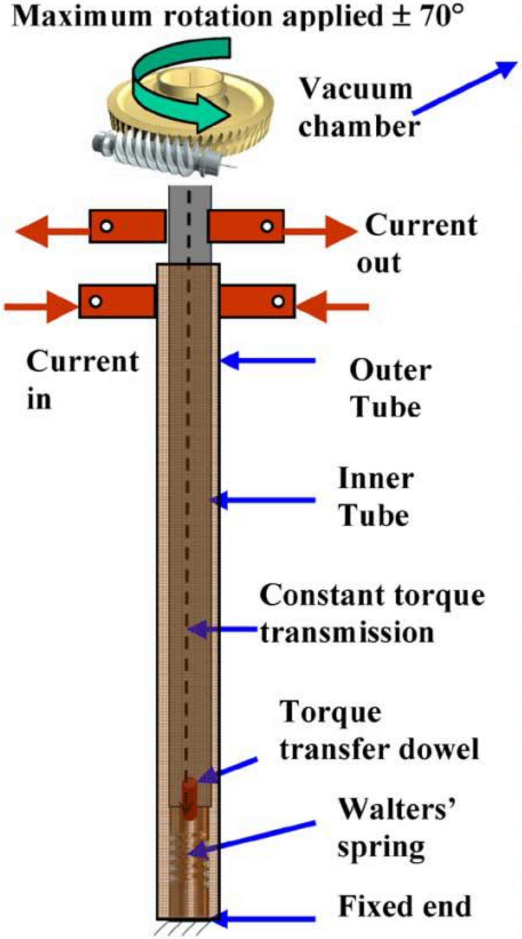
The Probe (1)

- The probe is made of two concentric OFHC tube copper tubes which act as current (2000A) and torque carriers (max 60 Nm);

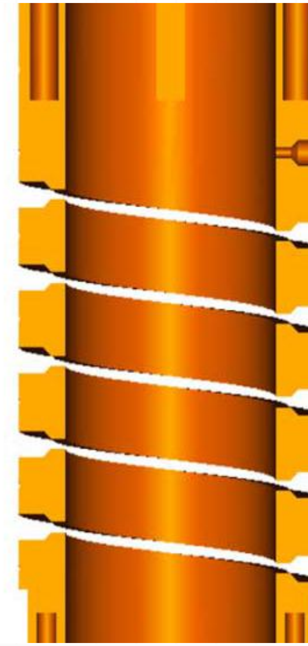
- The top of the spring is attached to the inner tube and can rotate, the bottom is fixed with the outer tube at the bottom end;
- Torque is generated through a manual worm gear and transferred to the sample through the spring.

- It uses a *bending spring technique*, more complex than the monotonic axial loading but it allows to test longer sample, up to ~800 mm;
- It also makes possible to transfer both tensile and compressive stress state, the latter is important dealing with thermal load.



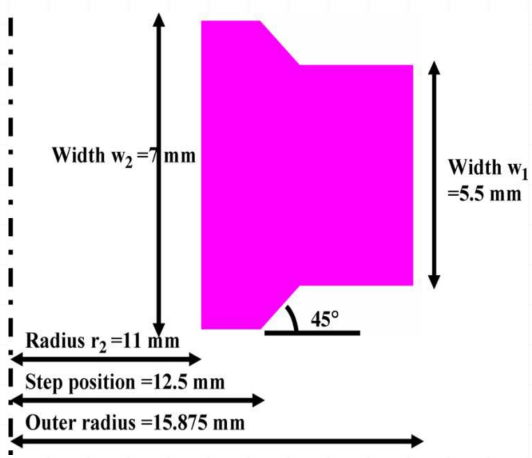
(1) Emanuela Barzi et al
'Design of a Probe for Strain Sensitivity Studies of Critical Current Densities in Superconducting Wires'

Walter Spring



- The spring is the core part of the probe. It is made of Ti-6Al-4V alloy which guarantee higher elasticity limit, ~1.3% but poor solderability.

The cross section is T-shaped with a groove to place the specimen.



The geometry is optimized in order to:

- minimize the strain ratio between the inner and outer surface of the spring
- Reduce the strain gradient across

the wire or tape to be measured.

Calibration

- We have to verify the computed (analytically and with FEA) relation between the imposed angular displacement θ on the spring with the strain ε obtained with a proper calibration using <u>strain gauges</u>

GOAL $\varepsilon = \varepsilon(\theta)$

Objectives

We want to check:

- Linearity
- Hysteresis
- Reproducibility
- Different prestrains with different installation configuration
- Thermal expansion coefficient match between spring and specimen
- Strain uniformity along the spring

The aim is to positively verify these conditions in order to validate the model and not to have installed the strain gauge during operative use of the probe.

Analytical Model

- **STRAIN**

The spring is treated as a curved beam, each turn represents a curved section, we get the circumferential strain:

$$\varepsilon_{\theta\theta} = K(1 - r_n/r)$$

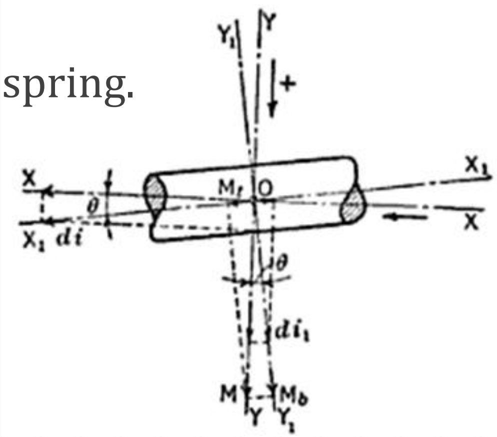
where K is a factor that depends on the *applied angular displacement*, the *number of turns* of the spring and the *pitch angle*, and r_n is the radial position of the neutral axis.

- **GEOMETRY**

We exploited this scheme representing an element of the spring.

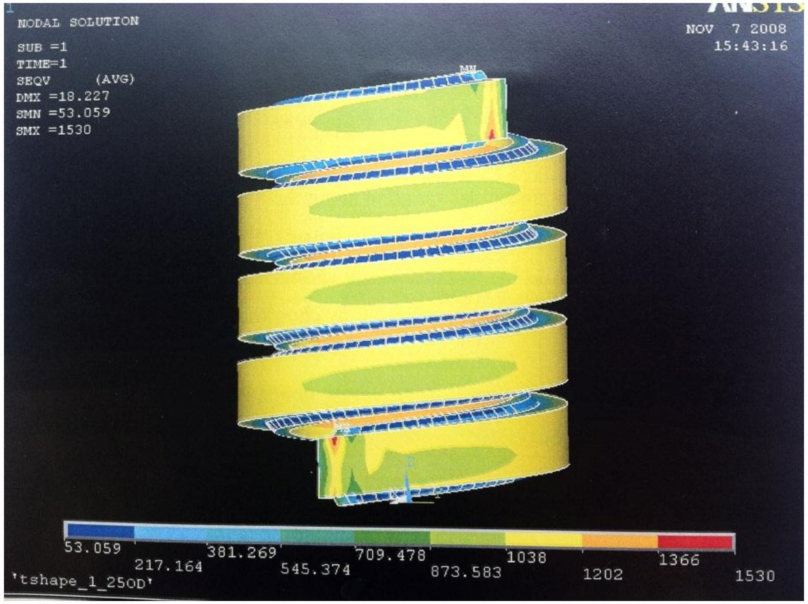
We compute the variation in:

- Mean diameter
- Angular distortion of turns
- Total vertical length



Finite element model

- To verify the analytical solution and to simulate the spring behavior at cryogenic temperatures, a finite element model was developed (1)
- It shows a sinusoidal behavior which differs from analytical solution.

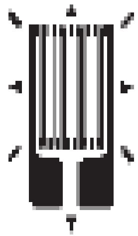


(1) Nandhini et al
'Design of a Probe for Strain Sensitivity Studies of Critical Current Densities in Superconducting Wires'

Measuring strain: STRAIN GAUGE

There are several aspects that we need to take into account:

- **Thermal expansion**: there are self temperature compensated SG, we have to check if they match with our material or we have to use dummy gauge;
- **Numbers**: we need to define how many transducers are necessary to obtain a significant representation;
- The **strain component** we want to catch and so the direction of installation;
- **Wheatstone bridge** configuration.



SG Set-up

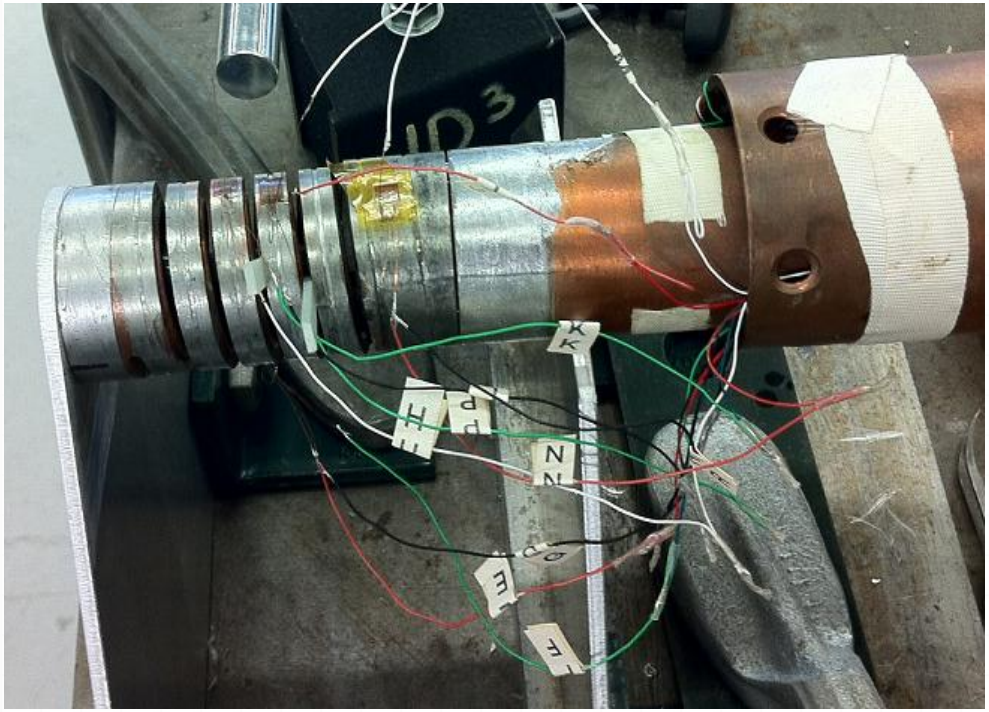
We place 4 strain gauges on the spring .

3 Active SG :

- located on the 2 central turns, 180 degrees apart
- quarter Wheatstone bridge
- oriented through the longitudinal direction to catch the *helical strain* (circumferential)

Dummy gauge

- laid, not glued, on the upper part of the spring
- half bridge configuration.

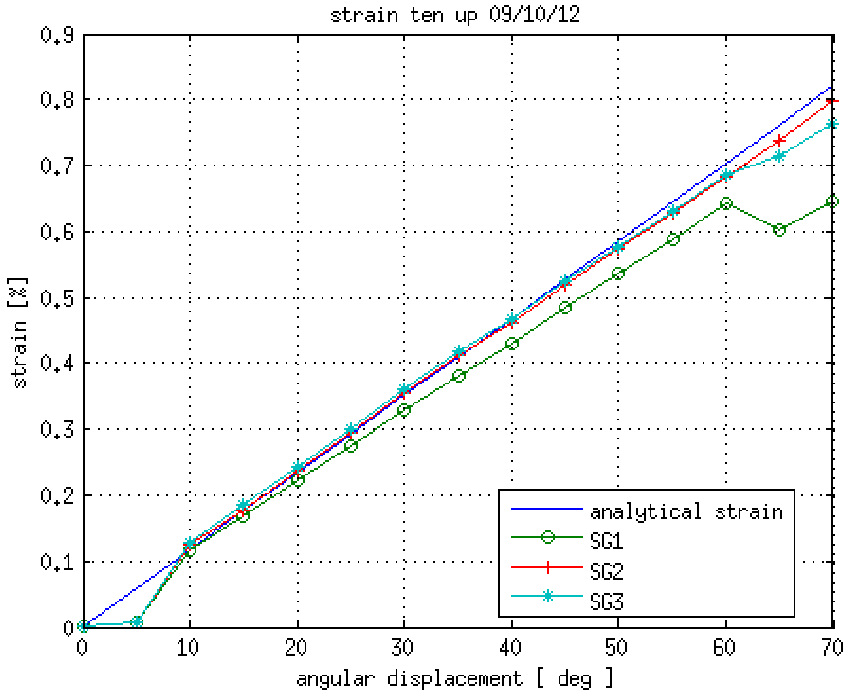


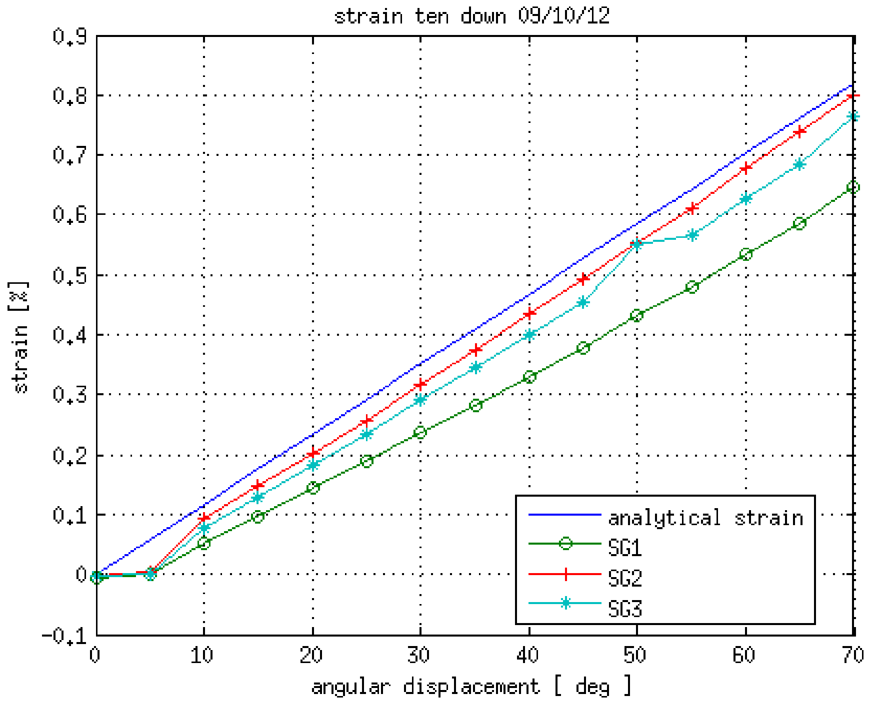
Operation

- We act on worm-gear to transfer the strain through the inner tube to the spring.
- We go from 0 to +70 degrees inducing a **tensile** strain state.
- Then we do the same but from 0 to -70 degrees causing a **compression** strain state on the spring.
- We use step increase of 5 degrees in order to have a proper resolution on the angular displacement scale.

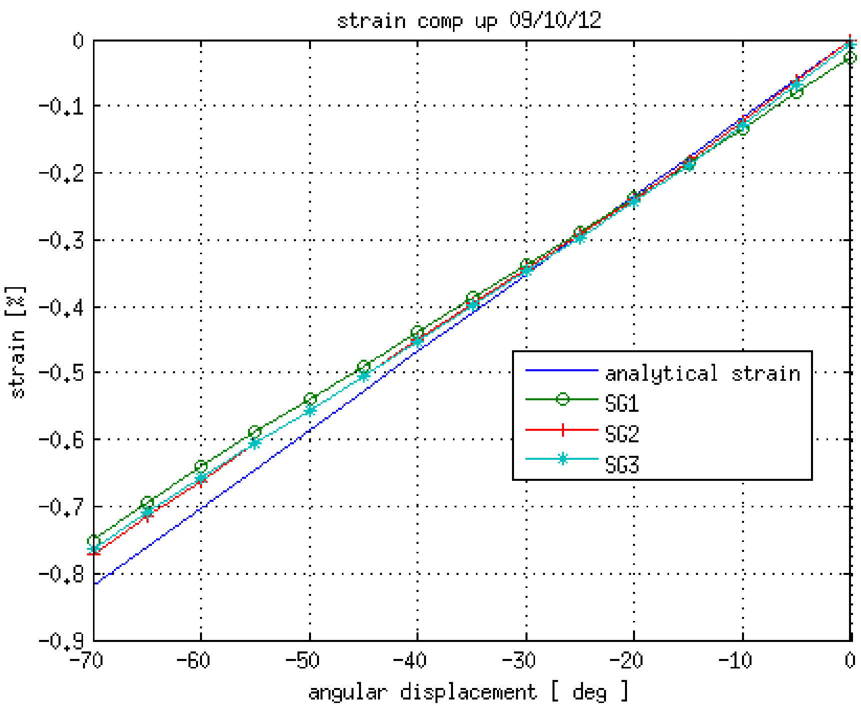
- Devices numbering: SG2 is in between SG1 and SG3, following the helical path from the bottom of the spring.
- SG3 is the one connected with dummy

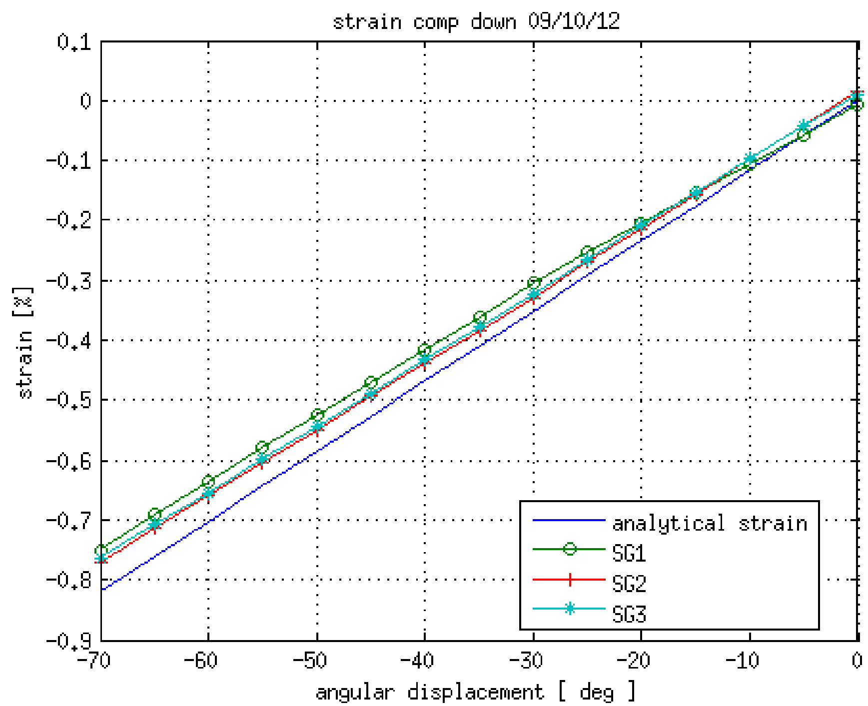
Results
Strain –Tension





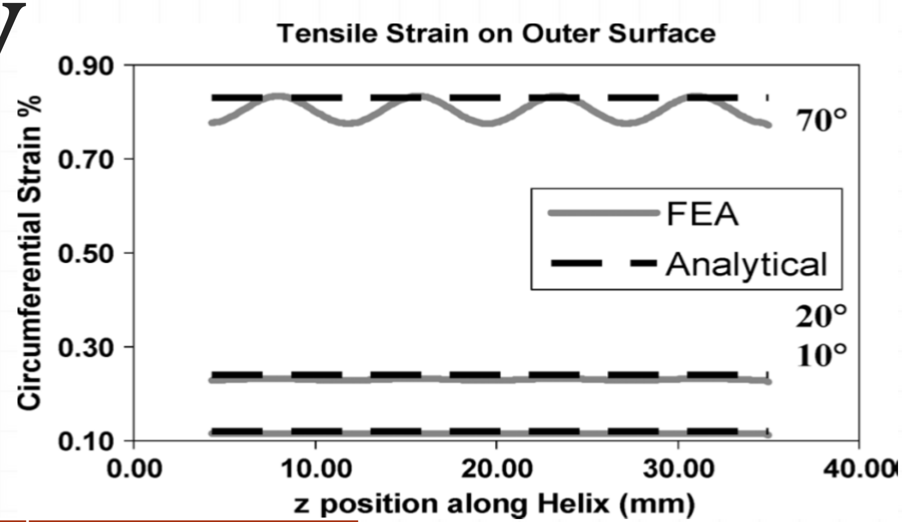
Results
Strain –Compression





Strain uniformity

- FEA predicts sinusoidal behavior of strain along the helical path.



	10 degrees	20 degrees	70 degrees
Expected Amplitude	$1 \cdot 10^{-5}$	$2 \cdot 10^{-3}$	$2.5 \cdot 10^{-2}$
Difference between SG2 and SG1	$0.7 \cdot 10^{-4}$	$1.65 \cdot 10^{-3}$	$1.52 \cdot 10^{-2}$
Difference between SG3 and SG1	$1.2 \cdot 10^{-4}$	$2.23 \cdot 10^{-3}$	$1.167 \cdot 10^{-2}$

- Strain gauge data

Error Analysis

The different sources of errors are:

- Hysteresis
- Zero-offset: due to impedance difference
- Cables impedance
- Installation effect
- Uncertainties on gauge factor and strain gauge resistance
- EMI induced errors: due to amplification

Next Step

- FEA on transverse strain and thermal load
- Use different spring material
- Testing at 4.2 K